NATIONAL PARK SERVICE

ALASKA REGION

WALKER LAKE FIREWOOD SURVEY,

GATES OF THE ARCTIC NATIONAL PARK AND PRESERVE - 1986

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REPORT ON THE

WALKER LAKE FIREWOOD SURVEY

IN

GATES OF THE ARCTIC NATIONAL PARK AND PRESERVE

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INTRODUCTION

Subsistence use of wood is allowed in Alaskan units of the National Park Service (36 CFR, sec. 13.49). The regulations stipulate that live trees less than 3 inches basal diameter and dead or down wood can be taken without a permit whereas a permit is needed to cut live trees over 3 inches basal diameter. All wood removal, however, is subject to the conditon that it be compatible with the purposes for which the park area was established. A subsistence user's request to collect firewood around Walker Lake in Gates of the Arctic National Park, and, specifically, to cut live birch, created a need for information on the long term potential for harvesting firewood around the lake. Ahlstrand collected data at Walker Lake in 1981 on growth rates and size class distribution in several small plots of white and black spruce, but did not estimate wood volumes.

The objectives of the present study were several:

1. To evaluate the feasibility of the subsistence user's request for 3 cords of green birch per year and 5 cords of dead/down wood and, in general, to assess the volume of wood available for firewood in one area of the lakeshore and
2. To estimate the ability of this area to sustain yearly wood harvests by estimating tree growth rates and the regeneration potential.

METHODS

Inventory Design

Data collection procedures for this firewood survey were developed by Tony Gasbarro and George Sampson. Inventory design and the amount of data that could be collected were constrained by limited human and financial resources; the resulting estimates of wood volumes and productivity are not statistically valid due to the small sample sizes. It should be stressed, also, that this is not a complete firewood inventory of the Walker Lake area; the mosaic nature of the vegetation around the lake means that care should be taken in extrapolating the results of this study to the entire lake area.

Data were collected by GAAR FIREPRO personnel, Nancy Van Alstine, Janet Christiansen, and Sheryl Stevens, VIP's Mary Jane Murphy and Suzanne Hosier, and Park Rangers Dave Buchanan and Jay Robinson. Sampling was conducted July 15 - 18 and parts of July 24 and August 12, 1986, for a total of 5 days.

The study area (elevation: 750 ft), 3.5 miles along the southwestern shore of the lake (Fig. 1), was selected because the subsistence user indicated that this was an area from which he would collect or had collected. Some evidence of wood harvesting, both birch and spruce, was found in the course of this study. The vegetation of the area is characterized by a mosaic of black spruce (*Picea mariana*), white spruce (*Picea glauca*), and paper birch (*Betula papyrifera*) stands interspersed with strips of alder (*Alnus crispa*). Slope ranged from 3% to 30%

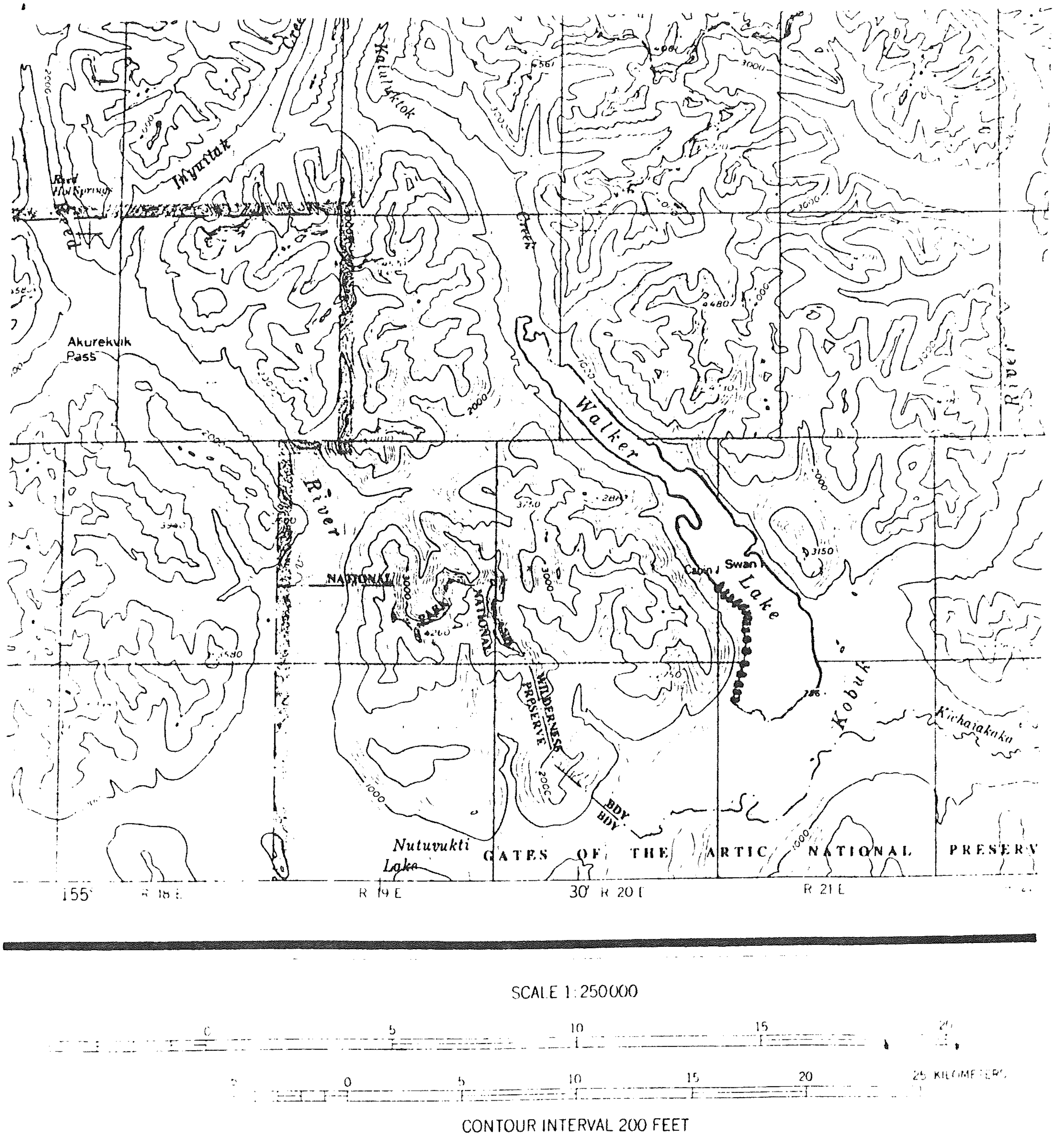

Fig. 1. Location of the 1986 firewood survey on the southwestern shore of Walker Lake.

in the plots sampled.

Sampling was done within a series of "nested" circular plots. Twenty-five sets of "nested" plots were completed, so a total of 5 acres or 2% of the study area of 213 acres was sampled. The plots were located along 9 lines running west from the lakeshore, with each line containing 3 plots each. The lines of plots were 1800 feet apart. The distances between lines were not measured out with a tape measure due to the difficulty of maneuvering through the vegetation; instead, the 1800 ft between lines 1 and 2 were measured with a tape measure, the time it took the NPS motor boat to travel between these two lines at full throttle was determined, and the remaining lines were marked out using the boat.

Plot centers were 150 feet apart and the first plot center was 150 feet from shore. The maximum depth in from the lakeshore was 503 feet, a distance that was assumed to be reasonable for someone to travel to collect and transport firewood back to the lakeshore. Plot centers were located using a compass and tape measure. The "nested" 1/5, 1/20, and 1/100 acre plots were established by marking off concentric plots with radii of 52.7 ft., 26.3 ft., and 11.8 ft., respectively.

Within the 1/5 acre plot all trees greater than or equal to 9" diameter at breast height (DBH; breast height = 4.5 ft) were measured for diameter and total height. One tree in each 2 inch diameter class (9.0" - 10.9", 11.0" - 12.9", etc.) was bored with an increment borer at DBH height to obtain the last 10 annual rings; these were used to determine growth rates. Cores were stored on grooved wood blocks.

Within the 1/20 acre plot all trees from 2.5" DBH, (approximately 3" basal diameter), to 8.9" DBH were measured for DBH and height and 10 year growth cores were extracted from each 2" diameter class.

Tree heights, diameters, and cores were also taken in the 1/5 acre plots to determine site index. Site index is a measure of site quality or productivity. It is based on tree height at a given base year and serves as a means of comparison between sites. Site index for white spruce is based on 100 years and for paper birch, 50 years.

There are various methods used to determine site index. The method employed here was as follows: tree heights and complete cores (taken at 1 foot from the base) were extracted from 2 healthy dominant or co-dominant trees in each 1/5 acre plot. It was later discovered that breast-height age rather than basal age is usually used in determining site index, so basal ages were corrected by subtracting 7 years. A dominant tree is defined as a tree whose crown extends above the general level of the crown cover and which receives full sunlight from above and partly from the side. A co-dominant tree has a crown in the general level of the crown cover and receives full light from above, but little from the sides. Due to the open nature of the forests in this area, all trees sampled were dominants.

To determine the site index, tree heights were plotted against age for each species and the equation for the line of best fit was derived; site index was then calculated from the equation.

Also within the 1/20 acre plot, data on dead/down wood were recorded. The DBH and heights were measured on all standing sound snags and all sound downed wood whose stumps originated in the plot. If tops were broken off trees, total heights were estimated.

Within the 1/100 acre plots, trees less than 2.5" DBH were tallied by species. These trees were separated into those less than 4.5 ft. and those taller than 4.5 ft.

Lab Work

Facilities at the U.S. Forest Service Pacific Northwest Station, Fairbanks, Alaska, were used to age and measure the collected tree cores. NPS - Biological Technician Holli McClain assisted in aging and measuring the cores.

Derivation of Volume and Growth Rates

Tree volumes were derived in one of two ways. When DBH and heights were appropriate, volume tables (see Appendix) were used for white spruce and birch. In some cases when heights were just below the lowest height on the table, volumes were extrapolated from the table. For black spruce, and cases of white spruce not on the table, the following formula was used:

$$\text{Volume (cubic feet)} = .262 \times \text{Diameter}^2 \times \text{height}$$

This formula was derived from the formula for the volume of a cone.

Growth rates were derived using regression analysis on tree height vs. diameter (DBH). Tree diameters 10 years ago were calculated by subtracting twice the length of the 10 year growth core from the current diameter (DBH). Tree core lengths were corrected for shrinkage resulting from drying after extraction. The following correction factors were used:

White spruce	1.025 x	dried core length
Black spruce	1.03 x	dried core length
Paper birch	1.052 x	dried core length

Tree height 10 years ago was derived from the regression equation (Equations included in appendix) and then using tree height and diameter 10 years ago the volume was taken from the volume tables (see appendix). For each species, a factor was developed in which the volume 10 years ago was expressed as a percentage of current volume and then, using these factors, the volume 10 years ago was estimated for all the trees measured in each plot. The annual growth rate was then calculated for each tree by the following equation:

$$\text{growth rate} = (\text{current vol.} - \text{vol.10 years ago}) / 10$$

Finally, an average annual growth rate for each species in the study area was calculated. It should be noted that the diameter and tree height data from this study did not give a strong regression relationship, a result, most likely, of the large range in site variability.

DATA ANALYSIS

Due to the small number of plots sampled and the high variability between plots, the data reported here should not be accepted as absolute figures, but should be viewed for broad trends.

Standing Volume

The standing volume data, presented in Tables 1 and 2, below, indicate that the majority of wood volume in the study area is in white spruce (56%), followed by birch (27%), and black spruce (17%). Both white spruce and birch are commonly taken for firewood, although only a permit to cut birch has been requested by the subsistence user in this case. Black spruce, although a more efficient heat source (Hale 1952), is generally not collected due to its small size, many branches,and difficulty in stacking.

Table 1. Standing volumes, volume per acre, in the Walker Lake study area.

Volume, cubic feet/acre

Species	DBH Class		Total
	> 9"	2.5 - 8.9"	
White spruce	49.00	59.14	108.14
Paper birch	4.58	47.84	52.42
Black spruce	0	33.34	33.34
Total	53.58	140.32	193.90

Table 2. Total standing volumes in the 213 acre Walker Lake study area.

Volume, cubic feet

Species	DBH Class		Total
	> 9"	2.5 - 8.9"	
White spruce	10437	12597	23034
Paper birch	976	10190	11166
Black spruce	0	7101	7101
Total	11413	19798	41301

In Table 3, the volume of white spruce and paper birch is expressed in cords of wood; a figure of 77 cubic feet/cord was assumed. At 3 cords of birch harvested per year, the 145 cords of birch in the study area represent a 48 year supply, if replacement/regeneration is not considered.

Table 3. Standing volumes of white spruce and paper birch, expressed in cords per acre and total number of cords,in the Walker Lake study area.

Volume, cords

Species	Cords/acre	Total cords
White spruce	1.40	298
Paper birch	.68	145

Growth Rate

Table 4. Annual growth, volume/acre/year, in the tree species at the Walker Lake study site between 1976 and 1986.

Species	Volume, cubic feet/acre/year DBH Class		Total
	> 9"	2.5 - 8.9"	
White spruce	0.85	1.54	2.39
Paper birch	0.02	0.41	0.43
Black spruce	0	0.68	0.68
Total	0.87	2.63	3.50

The annual growth data are presented in Table 4. The major portion of the annual growth is in white spruce (68%), mainly in the trees from 2.5" to 8.9" DBH. Birch annual growth per acre is only 12% of the total wood production, lower even than that of black spruce which represents 17% of the total.

The total wood production per year in the trees with greater than 3 inches basal diameter is shown in Table 5 below.

Table 5. Total annual growth, expressed in both cubic feet and cords, between 1976 and 1986 in the Walker Lake study area (213 acres).

Species	Total volume/year cubic feet	cords
White spruce	509	6.6
Paper birch	92	1.2
Black spruce	145	1.9

Based on the annual wood production of birch and removal of 3 cords of birch per year by the subsistence user, and ignoring regeneration for the moment, there would be a net loss of birch from the study area, if it were the only area harvested.

Stocking of Young Growth

The data collected for trees with basal diameter less than 3 inches represents an estimate of the stocking or density of trees that would not be taken for firewood, some of which would eventually become fuelwood size. These densities are shown in Table 6 below:

Table 6. Tree densities, trees/acre, and total numbers of trees less than 3 inches basal diameter in the Walker Lake study area.

	Trees/acre		
Species	< 4.5 ft	> 4.5 ft	Total
White spruce	240	136	376
Paper birch	0	80	80
Black spruce	268	220	488

These data should be interpreted in light of the small sample size, small plot size, and high variability between plots: 16 plots had no white spruce young growth, 21 plots had no young birch, and 17 plots had no black spruce young growth. Not surprisingly the largest share of the small growth is in black spruce, a result of its more stunted growth form and layering habit; white spruce numbers, however, are not far behind. The numbers of young white spruce in this area are roughly equivalent to the numbers reported by Ahlstrand (1981) for a low elevation white spruce stand on the east side of Walker Lake. The number of small birch is low, 8% of the total, with all individuals in the over 4.5 ft category. Most, if not all, of these occurred as sprouts from the base of existing trees, rather than seedlings.

For comparative purposes Table 7 shows the density of the larger trees per acre, grouped in size classes, in the Walker Lake study area.

Table 7. Stocking density, trees/acre, of the trees > 2.5 inches DBH in the Walker Lake Study area.

	Trees/acre			
	DBH classes (inches)			
Species	2.5-4.9	5-9.9	10-14.9	>15
White spruce	24	15	2	0.2
Paper birch	16	5	0.4	-
Black spruce	66	6	-	-

Densities of the older trees (considering spruce only) are low in comparison with those found by Ahlstrand (1981) in the east side Walker Lake sites; the amount of young spruce growth in the southwestern lakeshore area, therefore, appears to be sufficient to replace the older trees if they were harvested. On the other hand, the data suggests there may not be enough young birch to replace the older birch trees if they were harvested.

Dead/Down Fuelwood

Table 8 presents the data for dead wood that could be used for firewood in the study area; trees with detectable rot were not counted.

Table 8. Volume of dead wood per acre and the total for the Walker Lake study area.

Species	Volume/acre		Total volume	
	cubic ft	cords	cubic ft	cords
White spruce	27	0.35	5751	75
Paper birch	7	0.09	1491	19
Black spruce	5.2	0.07	1108	14

The largest volume of dead wood is in white spruce; most of this dead white spruce wood is in standing snags (96%), while the small remainder is in downed trees. If only the white spruce dead wood were collected, a realistic assumption since it is usually the largest and soundest dead wood, it will take approximately 14 acres to supply the 5 cords of dead wood per year that the subsistence user wants. The current supply of dead wood in the study area represents 15 years supply, if only white spruce were collected, and 22 years supply, if the dead wood of all species were collected.

Site Index

Figures 2, 3, and 4 show tree ages plotted against heights, the derived line of best fit, and the calculated site indexes for white spruce, paper birch, and black spruce, respectively. The white spruce data formed 2 distinct clusters with site indexes

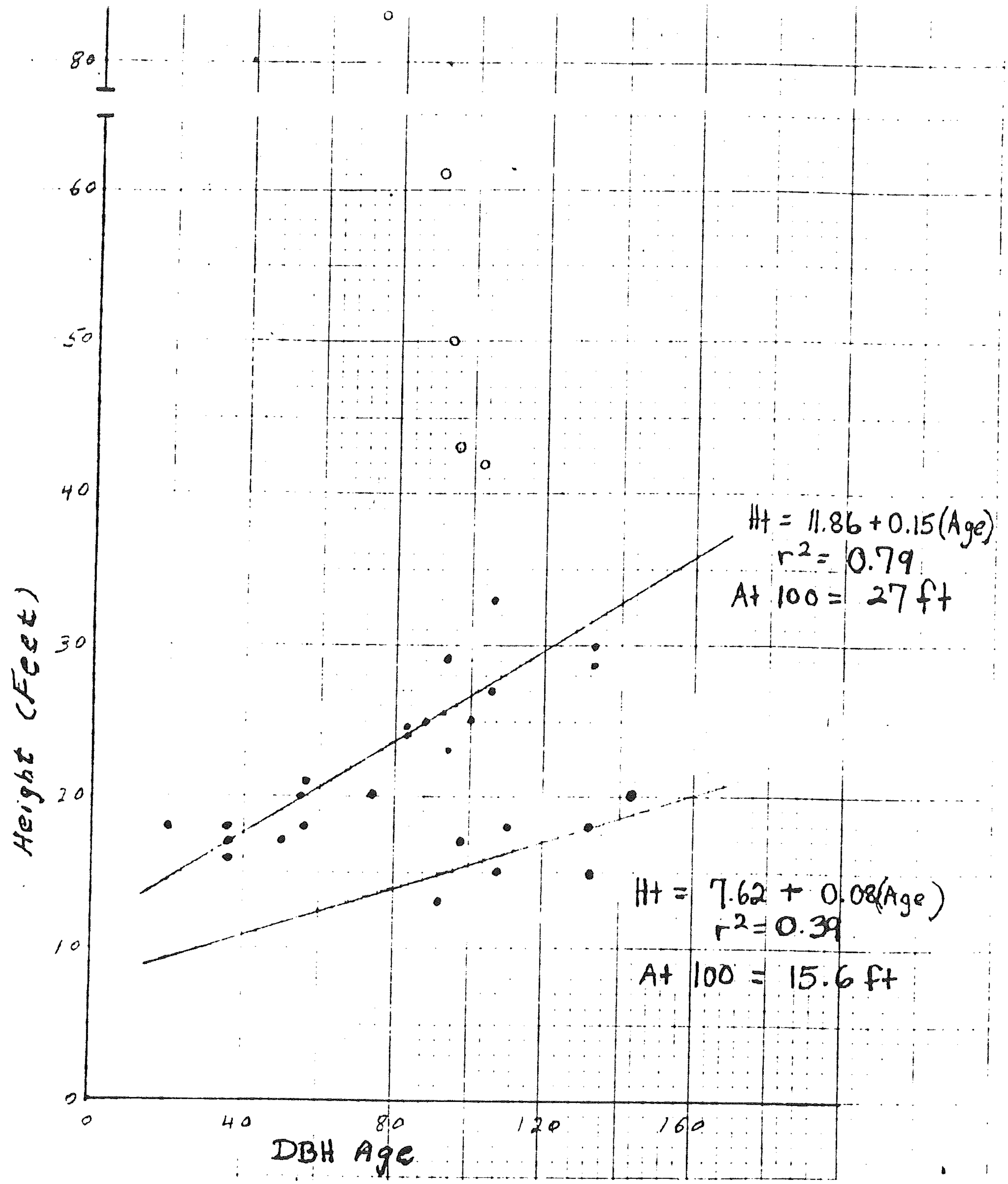

Fig. 2. White spruce tree ages plotted against heights, the derived lines of best fit, and the calculated site indexes for the Walker Lake study site. Trees indicated by open circles were omitted from the calculations.

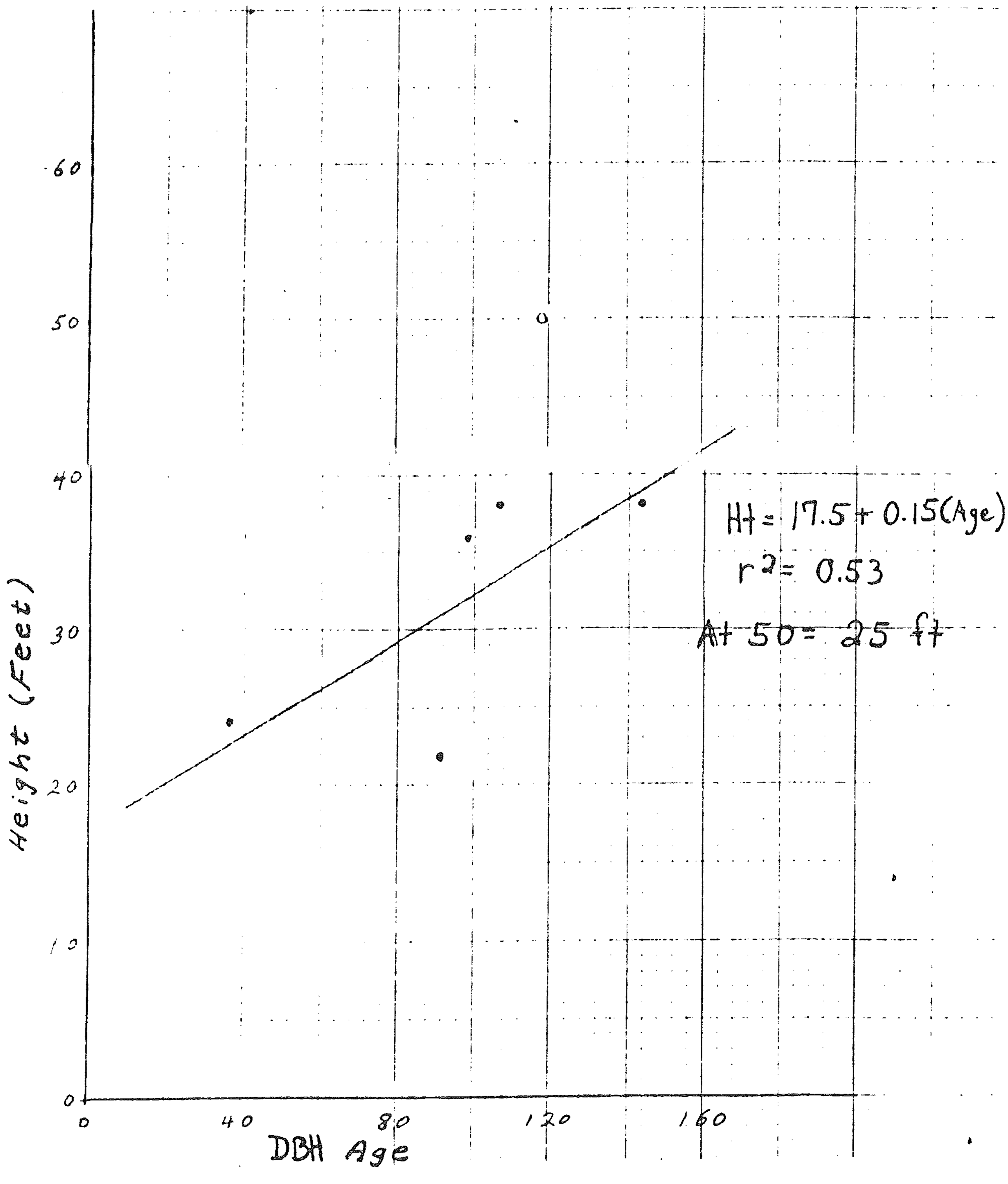

Fig. 3. Paper birch tree ages plotted against heights, the derived line of best fit, and the calculated site index for the Walker Lake study site. The tree indicated by the open circle was omitted from the calculations.

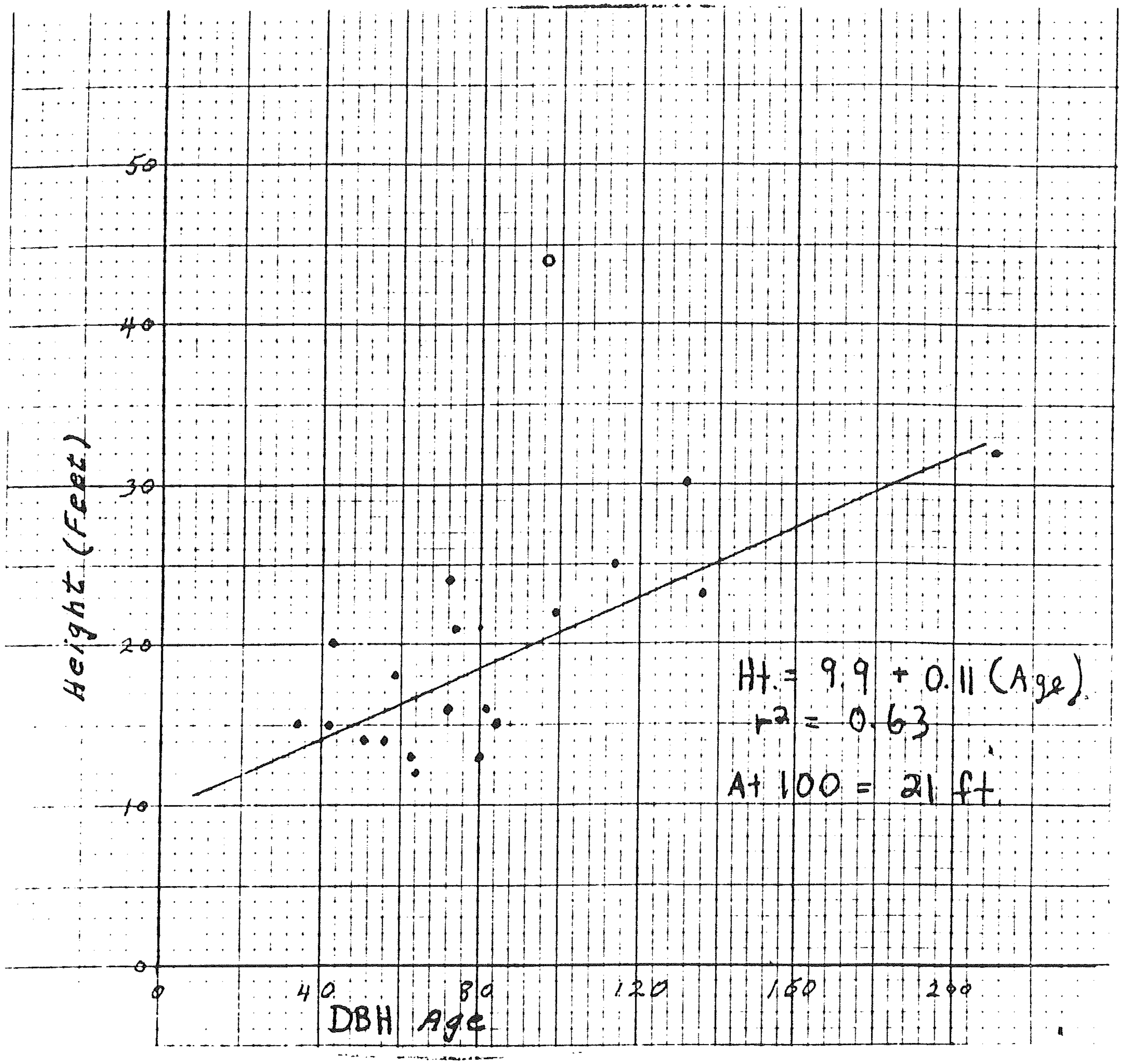

Fig. 4. Black spruce tree ages plotted against heights, the derived line of best fit, and the calculated site index for the Walker Lake study site. The tree indicated by the open circle was omitted from the calculations.

(height at 100 years) of 27 and 15.6; these distinct clusters probably represent microsite differences. The low productivity of this Walker Lake site is shown when comparison is made with average white spruce indexes from other sites in interior Alaska: Porcupine River, 55; Tanana River uplands between Fairbanks and Nenana, 84; and Copper River plateau, south of Glennallen, 58 (Farr 1967). The site index (height at 50 years) for birch at Walker Lake was 25, compared with a range of 35 to 65 at interior Alaska sites (Gregory and Haack 1965).

Tree Ages

To further characterize the Walker Lake study area the average ages and ranges of ages for the dominant trees sampled are shown in Table 9. These do not represent an average age for all the trees of a species in the plots, but rather the large, although not necessarily the largest, healthy trees.

Table 9. The average age and range of ages of the dominant trees sampled in the Walker Lake study area.

Species	Average age	Range of ages
White spruce	96	27 - 150
Paper birch	105	43 - 150
Black spruce	90	41 - 217

CONCLUSIONS

Evaluation of the Subsistence Users' Request

The data indicate that, in this area of the lakeshore, paper birch is about half as abundant as white spruce as a source of firewood. With the annual growth rate of birch low, young birch scarce, and the fact that large scale birch regeneration from seedling establishment requires major disturbance such as fire, annual harvesting of birch in this study area could result in a net loss of this species. On the other hand, the extent to which cutting birch would stimulate regeneration by sprouting is unknown. Sprouting in birch can be stimulated by cutting young vigorous growth, but the effect of cutting older trees is uncertain (Hutnik and Cunningham 1961). The dominant birch trees that were aged in the Walker Lake study site ranged from 43 - 150 years; all but one were over 96 years old. All of the birch in the plots were not aged, but by correlating tree height with age from Fig. 3, it appears that 2/3 of the birch sampled were 50 years or older. The potential for birch regeneration by means of sprouting, therefore, may be low in this area. Based on the available data on current birch regeneration and the regeneration potential, therefore, the sustained yield harvest of birch in the study area does not appear possible.

The current volume of dead wood that could be collected from this study area for firewood represents a 15 year supply, at 5 cords per year, if only white spruce is collected, 22 years supply if the sound dead of all species is collected. These figures do not take into account mortality rates or the rate at which burnable dead wood becomes too rotten to burn. There is no data on mortality rates in this area. Field experience has shown that the wood of standing spruce can last for years, but that standing birch and down spruce (approx. 6 - 7" DBH with bark intact) will rot in about 2 years.

Beyond the issue of whether the requested wood, both live and dead, is there in sufficient quantities for sustained collection is the question of how this wood harvesting affects the maintenance of the natural diversity and character of the vegetation communities of Walker Lake, a major management goal of Gates of the Arctic National Park. Are there changes in the natural ratio of dead to live trees, species composition, age class distribution, and regeneration? What are the effects of removing all of the dead trees from an area in terms of the loss of nutrients that would have been returned to the ecosystem through natural decomposition processes (probably negligible) or the loss of nesting sites? There is currently no data to answer these concerns.

NPS RECOMMENDATIONS

Management

1. Species Harvested

This preliminary survey of one area of the lake indicates that live birch is not abundant on the southwestern shore and there may not be sufficient birch young growth to replace the older trees when they die or are removed. Birch may be more abundant on the southeastern shore, but, if the trees there are of the same general age as those of the southwestern shore, then a similar situation may exist in terms of low numbers of young trees and low potential for replacement by sprouting from cut stumps. Through natural processes, the paper birch around the lake will gradually disappear, being succeeded by spruce, unless there is a fire in the area to stimulate regeneration by both seedling establishment and sprouting (Foote 1983). Concentrating on harvesting birch for firewood will accelerate the loss of birch from the Walker Lake area. It is recommended at this time that the subsistence user take half birch/half spruce when harvesting the 3 cords of live trees.

2. Harvest Methods

A cooperative understanding should be established about the general methods and conditions for harvesting firewood, including the following: trees should be cut as close to the ground as possible so that protruding stumps are not left; slash from trimming branches should be scattered; harvesting shall not be done within some minimum distance from the shoreline to lessen the impact visible from the lake; cut trees or slash shall not be left on the beach (a cut spruce was found on the beach during this wood survey); and harvesting should be done during times of low visitor use.

3. Specific Cutting Sites

Gasbarro and Sampson (see separate recommendations in Appendix) have recommended division of the area into sectors and then assignment of the subsistence user to "patchcut" within a particular sector each year. In patchcutting, trees are removed in small groups. Setting up a sector system, however, may presume a more accurate inventory of the wood resources of Walker Lake than NPS currently has; even if harvesting were restricted to the area studied in this survey, variability was so high and birch so patchy, it could be difficult for the subsistence user to obtain the desired number of cords from a given sector. An advantage of the sector system is that a known harvest area could then be studied for regeneration effects. If NPS does not designate an area for cutting, then NPS personnel may have to initially accompany the subsistence user on firewood harvests if exact areas of cutting are to be set up as sites of regeneration studies.

Gasbarro and Sampson further recommend that damage to small trees be minimized, but that the duff (organic) layer be scarified to expose mineral soil; mineral soil is a more favorable environment for seed germination for both spruce and birch. If this soil exposure is desired, it will have to be done deliberately since it is unlikely that much incidental soil disturbance will occur with the small scale harvesting being done here.

The exact procedures of harvest selection sites may be best worked out in cooperation with the subsistence user.

Future Work

1. In the summer of 1987, a vegetation map of the Walker Lake area should be drawn, using the available high altitude color infra-red photographs and any aerial or groundtruthing work necessary. Emphasis should be placed on mapping the locations of paper birch.

2. With the cooperation of the subsistence user, a study could be started to answer questions about regeneration in areas where trees have been harvested. The results of such a study could clarify the issue of whether the sustained yield harvesting of birch is possible. If the subsistence user could identify exact locations of trees harvested in the past few years, long-term regeneration study plots could be established and monitored. Otherwise, study plots would be set up in sites of this year's harvest.

3. Since the regeneration studies must necesarily be long-term studies, some additional data could be collected in summer 1987 to direct management decisions on future birch harvesting. The areas of birch on the southeastern lakeshore should be examined. Cores should be taken to determine the general age of the birch

trees in this area and how this compares with the age data for the southwest lakeshore; this could give an idea of the potential for sprouting if birch were harvested here. Data could also be collected on size class tree densities to determine if there is sufficient young growth currently to replace harvested older trees.

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APPENDIX

RECOMMENDATIONS TO GATES OF THE ARCTIC NATIONAL PARK AND PRESERVE ON FIREWOOD HARVEST AT WALKER LAKE

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1. To promote scarification and hence seedling establishment, the subsistence user should be encouraged to make small patchcuts. That is, he should remove the trees that he takes in small groups as much as possible. While doing this he should try to minimize damage to any small trees that are on the site, but should scarify the duff layer where there are no trees.

2. For esthetic reasons, it would be desirable to select the area for the subsistence user to harvest each year. As a first step, this will require agreement between the National Park Service and the subsistence user on how far from the lake he will go in taking wood. The National Park Service can then establish a general harvesting plan and assign a given area for harvest each year.

3. To facilitate Recommendation 2, it will be necessary to develop a map showing the entire harvest area divided into sectors. The subsistence user can then be assigned to one of the sectors for each year's harvest.

4. We recommend that investigation be made of the amount of seedling and sprout reproduction that has occurred on recently cutover areas. Hardwood sprouts should develop the year after harvest. It may take several years for seedlings to develop due to no seed production in some years. Observations on stocking after harvest should be confined to areas cut three or more years earlier. These observations on stocking can be made in the summer of 1987 if cutting areas of 1984 and earlier can be located.

5. Areas cut in 1987 and subsequent years should be recorded on a map to facilitate finding them to check stocking in future years and to facilitate rotating the cutting areas for aesthetic reasons.

6. Since maintenance of the current character of the visual resource is one goal of management, it is suggested that three or more photo points be established in the areas to be harvested. Photographs should be taken from these points at the same date, same time of day each year to maintain a permanent record of changes in the appearance over time.

PAPER BIRCH (*Betula papyrifera* Marsh.)

TOTAL VOLUME, I. B.

D.B.H.	TOTAL HEIGHT (FEET) 15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	B... No. tr
Inches	Cubic feet																
1	0.04	0.08	0.10	0.11													-
2	.17	0.22	0.27	0.31	0.37	0.40											
3	.26	.3?	0.52	0.65	0.75	0.85	0.95	1.5									1
4	.5?	.8?	0.95	1.1	1.3	1.5	1.6	1.8	2.0	2.2							1
5	.7?	1.1	1.4	1.7	2.0	2.3	2.5	2.8	3.1	3.4	3.6	3.9					2
6			2.1	2.5	2.9	3.3	3.6	4.0	4.4	4.8	5.2	5.6	6.0	6.4			2
7				3.3	3.9	4.4	4.9	5.5	6.0	6.5	7.1	7.6	8.1	8.6			4
8						5.7	6.4	7.2	7.8	8.4	9.1	9.7	10.4	11.0	11.7		4
9					6.4	7.2	8.0	8.9	9.7	10.5	11.3	12.1	13.0	13.8	14.6	15.4	4
10					7.3	8.8	9.8	10.8	11.8	12.8	13.8	14.8	15.8	16.8	17.9	18.9	4
11						10.5	11.7	12.9	14.1	15.4	16.6	17.8	19.0	20.2	21.4	22.7	3
12							13.8	15.2	16.7	18.1	19.6	21.0	22.5	24.0	25.4	26.9	2
13							16.0	17.8	19.5	21.2	22.9	24.6	26.3	28.0	29.7	31.4	1
14								20.5	22.5	24.4	26.4	28.4	30.4	32.4	34.3	36.3	
15								23.4	25.7	28.0	30.2	32.5	34.8	37.0	39.3	41.6	
16									29.1	31.7	34.3	36.9	39.5	42.0	44.6	47.2	
17										35.7	38.6	41.6	44.5	47.4	50.3	53.2	-
18										40.0	43.2	46.5	49.8	53.0	56.3	59.6	-

Standard error of estimate = 9.68 percent.
Aggregate deviation = 0.12 percent.
Basis of table: 340 trees
Volumes above dashed line computed by combined variable method with graphical solution.

Volumes below dashed line computed by combined variable method with least squares solution giving formula: $V = 0.202\ X + 0.69$ where V = volume and $X = D^2H/100$.
Range of data enclosed by solid line.

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PAPER BIRCH (*Betula papyrifera* Marsh.)

MERCHANTABLE VOLUME, I. B. — 1-FOOT STUMP, 4-INCH TOP

D.B.H.	TOTAL HEIGHT (FEET) 30	35	40	45	50	55	60	65	70	75	80	85	90	Basis
Inches	Cubic feet													No. of trees
5	0.46	.70	.88	1.1	1.3	1.7	2.0	2.2	2.6					18
6	1.1	1.5	1.8	2.2	2.7	3.2	3.6	4.0	4.4	4.7	5.2			22
7	1.9	2.5	3.2	3.6	4.2	4.7	5.3	5.9	6.4	6.9	7.4			46
8			4.5	5.1	6.0	6.6	7.2	7.9	8.5	9.2	9.8	10.5		42
9			6.0	6.8	7.7	8.5	9.3	10.2	10.9	11.8	12.6	13.3	14.0	42
10			7.6	8.6	9.6	10.6	11.6	12.6	13.5	14.5	15.4	16.5	17.4	48
11			9.3	10.5	11.7	12.8	14.0	15.3	16.4	17.5	18.8	19.9	21.1	37
12				12.6	13.8	15.4	16.6	18.0	19.5	20.9	22.3	23.6	25.0	25
13				14.7	16.4	17.9	19.7	21.3	22.9	24.4	26.0	27.9	29.5	13
14					19.1	20.9	22.7	24.6	26.4	28.6	30.4	32.2	34.1	4
15					21.8	23.9	26.0	28.4	30.6	32.7	34.8	36.9	39.1	3
16						27.4	29.8	32.2	34.7	37.1	39.5	41.9	44.4	1
17							33.6	36.3	39.1	41.8	44.6	47.3	50.0	—
18							37.6	40.6	43.7	46.8	49.8	52.9	56.6	—

Aggregate deviation = 0.31 percent.
Basis of table = 301 trees.
Merchantable volumes computed as percent of total volume. Percent adjustment based on free hand curve of percent merchantable over $D^2H/100$.
Range of data enclosed by solid line.

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Table 2.--Tree volumes inside bark (entire stem) for white spruce, interior Alaska 1/

D.B.H. 2/ Inches	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	BA Number of tr
	TOTAL HEIGHT, H (FEET) 3/ Cubic feet																				
4	.8	1.0	1.3	1.5	1.7	2.0	2.2	2.4	2.6												--
5	(1.4)	(1.7)	(2.1)	(2.4)	(2.7)	(3.0)	3.3	3.6	3.9	4.3	4.6										28
6	2.1	(2.6)	(3.0)	(3.4)	(3.8)	(4.2)	(4.6)	(5.1)	5.5	5.9	6.3	6.7									24
7	3.0	(3.5)	(4.0)	(4.6)	(5.1)	(5.7)	(6.2)	(6.7)	(7.3)	(7.8)	8.4	8.9	9.4	10.0	10.5						31
8	(3.9)	4.5	5.2	(5.9)	(6.6)	(7.3)	(7.9)	(8.6)	(9.3)	(10.0)	(10.7)	11.3	12.0	12.7	13.4	14.1					34
9	4.9	5.7	6.5	7.4	(8.2)	9.1	(9.9)	(10.7)	(11.6)	(12.4)	(13.3)	(14.1)	(14.9)	15.8	16.6	17.4					28
10		7.0	8.0	(9.0)	10.0	(11.0)	(12.1)	(13.1)	(14.1)	(15.1)	(16.1)	(17.1)	(18.2)	(19.2)	20.2	21.2	22.2				35
11		8.4	9.6	10.8	12.0	(13.2)	(14.4)	(15.6)	(16.8)	(18.1)	(19.3)	(20.5)	(21.7)	(22.9)	(24.1)	25.3	26.6				35
12			11.3	12.7	14.1	15.6	(17.0)	(18.4)	(19.8)	(21.3)	(22.7)	(24.1)	(25.6)	(27.0)	28.4	29.8	31.3	32.7	34.1		39
13			13.1	14.8	16.4	18.1	19.8	(21.4)	(23.1)	(24.8)	(26.4)	(28.1)	(29.7)	(31.4)	(33.1)	34.7	36.4	38.0	39.7		48
14			15.1	17.0	18.9	20.8	(22.7)	(24.7)	26.6	(28.5)	(30.4)	(32.3)	(34.2)	(36.1)	(38.1)	(40.0)	41.9	43.8	45.7	47.6	34
15			17.2	19.4	21.6	(23.7)	25.9	28.1	(30.3)	(32.5)	(34.7)	(36.9)	(39.0)	(41.2)	(43.4)	(45.6)	47.8	50.0	52.2	54.3	25
16				21.9	24.4	26.9	29.3	(31.8)	(34.3)	36.8	39.2	(41.7)	(44.2)	(46.7)	(49.1)	(51.6)	54.1	(56.6)	59.0	61.5	17
17				24.6	27.4	30.1	32.9	35.7	38.5	(41.3)	(44.1)	(46.8)	(49.6)	(52.4)	(55.2)	(58.0)	(60.8)	(63.6)	66.3	69.1	18
18					30.5	33.6	36.7	39.8	43.0	46.1	49.2	52.3	55.4	(58.5)	(61.6)	(64.7)	(67.8)	(71.0)	74.1	77.2	12
19						37.3	40.7	44.2	47.7	51.1	54.6	(58.0)	(61.5)	64.9	68.4	(71.9)	75.3	(78.8)	82.2	(85.7)	7
20						41.1	45.0	48.8	52.6	56.4	60.2	64.1	67.9	(71.7)	75.5	(79.4)	(83.2)	87.0	(90.8)	94.6	6
21								53.6	57.8	62.0	66.2	70.4	74.6	78.8	(83.0)	(87.2)	(91.4)	(95.6)	99.8	(104)	5
22								58.6	63.2	67.8	72.4	77.0	81.7	86.3	90.9	(95.5)	(100)	105	109	114	2
23										73.9	79.0	84.0	89.0	94.0	99.1	104	109	114	119	124	--
24										80.3	85.7	91.2	96.7	102	(108)	113	119	124	(130)	135	2
25												98.8	105	111	116	122	(128)	134	140	146	2
26												107	113	119	126	132	(139)	145	151	158	1
27												115	122	128	135	142	149	156	163	170	--
28												123	131	138	145	153	160	168	175	182	--
29												132	140	148	156	164	172	180	188	195	--
30												141	149	158	166	175	183	192	200	209	--
31												150	159	168	177	186	196	205	214	223	--
32												160	170	179	189	198	(208)	218	228	237	1

1/ Table volumes obtained from weighted regression equation: $V_T = -1.1843 + 0.2050D + 0.01639H + 0.00187D^2H$. Standard error of estimate around mean volume = 1.2982 cu. ft. = 4.9%.
2/ Mid-point of class (e.g. 4 = 3.6 through 4.5 inches).
3/ Mid-point of class (e.g. 25 = 22.6 through 27.5 feet).
4/ Figures in parentheses indicate extent of 434 measured trees used for computing above regression equation.

U. S. Forest Service, Research Note NOR-6

Regression equations used in determining annual growth

Using regression analysis, the following equations were developed for predicting total height based on diameter at breast height (DBH):

White spruce	Height = 4.32 + 3.9 DBH	$r^2 = .67$
Paper birch	Height = 16.50 + 3.12 DBH	$r^2 = .27$
Black spruce	Height = 0.41 + 4.47 DBH	$r^2 = .54$